Directional Polarimetric Camera stray light analysis calibration and correction

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The Directional Polarimetric Camera (DPC) [1] is a polarization sensor with character of ultra-wide-angle and low-distortion imaging [2–3] and developed by Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. It was launched successfully on May 9, 2018, aboard the GaoFen-5 Satellite (GF-5), a sun-synchronous orbiting satellite at an altitude of 705 km with an inclination of 98°, which has the 1:30 pm local overpass time and a 2-days revisiting period. The DPC is based on a Charge Coupled Device (CCD) matrix array detector and has effective pixels of 512×512 with a spatial resolution of 3.3 km under a swath width of 1850 km. It has 3 polarized bands (490, 670, and 865 nm) and 5 unpolarized bands (443, 565, 763,765, and 910 nm), providing as much as 9 viewing directions for an observing object. Its main mission is to obtain multi-angle, multi-spectral polarization radiation data, and combine the characteristics of atmospheric inversion model based on polarization information to provide global atmospheric aerosol and cloud characteristics data products, including aerosol optical thickness, particle size distribution, particle shape and cloud optical thickness, etc., so as to provide data support for atmospheric environment monitoring, global climate change and high accurate atmospheric correction [4–7].

Stray light [8–10] is referred to as the non-imaging light received by the detector. When non-imaging light reaches the surface of the detector, it forms stray radiation which will reduce the contrast and clarity of the image. In severe cases, the target image will be annihilated by stray light. For the DPC, stray light will cause the degradation of imaging quality, resulting in the measurement error of apparent reflectance or polarized reflectance, and adversely affecting the accuracy of radiation and polarization calibration and the inversion of aerosol parameters. In order to restrain stray light from reaching the image surface, general methods include installing a hood in front of the instrument objective, adding an anti-stray diaphragm in the design of the barrel, and coating the inner wall of the instrument with a black anti-glare paint, etc. However, the use of a hood can only reduce stray light outside the field of view (FOV), and the diaphragm and paint are limited by the level of technology. Thus, the adoption of these measures cannot completely eliminate stray light, especially for the DPC, which is a kind of large FOV imaging instrument. Stray light in the FOV is more difficult to eliminate if the above methods are merely used. Therefore, suitable stray light correction algorithm is needed for the further process of the measured image.

The stray light correction algorithm [11–16] is a kind of method which can eliminate stray light effectively by means of post-treatment. It has been widely studied and applied due to its convenience and no need to change the structure of the instrument. There are many reports on this topic. Lahrrère *et al*. [11] subdivided the stray light of the Polarization and Directionality of the

Earth's Reflectances instrument into the first type and the second type, and proposed the concept of using the deconvolution algorithm [17–21] to correct the first type of stray light and the matrix method to correct the second type of stray light. However, the specific implementation of the methods has not been given. Iwasaki et al. [12] established a parametric stray light function for the visible near infrared channel and infrared channel of the Advanced Spaceborne Thermal Emission Reflection Radiometer, and corrected the stray light by Van-Cittert iterative algorithm. Gerace *et al*. [13] deduced the position of stray light through the optical model of the Thermal Infrared Sensor and estimated the value of the stray light, thus realizing stray light correction by subtracting the estimated stray light data from the measured data. Zong *et al*. [14] obtained the stray light diffusion function of different pixel positions of the instrument detector, so as to construct the stray light correction matrix of the imaging system to achieve the correction of stray light. But this method is only suitable for a linear array CCD. It needs to be extended to two-dimensional form for stray light correction of an area array CCD.

In this paper, firstly, the working principle and the optical structure of the DPC are introduced, and the stray light characteristics of the instrument are analyzed based on its optical structure. Then, a novel deconvolution method is proposed to correct the local stray light and the matrix method is extended to two-dimensional form to correct the global stray light, respectively. Finally, stray light correction is carried out for laboratory images with the proposed methods. The experimental results show the effectiveness of the proposed correction methods.

References

[1] Li, Z. Q., W. Z. Hou, J. Hong, F. X. Zheng, D. G. Luo, J. Wang, X. F. Gu, and Y. L. Qiao, 2018: Directional Polarimetric Camera (DPC): monitoring aerosol spectral optical properties over land from satellite observation. *J. Quant. Spectrosc. Ra.* **218**, 21–37.

[2] Bian, Y. X., H. F. Li, Y. F. Wang, Z. R. Zheng, and X. Liu, 2015: Method to design two aspheric surfaces for a wide field of view imaging system with low distortion. *Appl. Opt.* **54**, 8241–8247.

[3] Sahin, F. E., and A. R. Tanguay, 2018: Distortion optimization for wide-angle computational cameras. *Opt. Express.* **26**, 5478–5487.

[4] Herman, M., J. L. Deuze, C. Devaux, P. Goloub, Francois-Marie Bréon, and D. Tanré, 1997: Remote sensing of aerosols over land surfaces including polarization measurements and application to POLDER measurements. *J. Geophys. Res.* **102**, 17039–17049.

[5] Deuze, J. L., F.M. Bréon, C. Devaux, P. Goloub, M. Herman, B. Lafrance, F. Maignan, A. Marchand, F. Nadal, G. Perry, and D. Tanré, 2001: Remote sensing of aerosols over land surface from POLDER-ADEOS-1 polarized measurements. *J. Geophys. Res*. **106**, 4913–4926.

[6] Vachon, F., A. Royer, M. Aube, B. Toubbe, N. T. O'Neill, and P. M. Teillet, 2004: Remote sensing of aerosols over North American land surfaces from POLDER and MODIS measurements. *Atmos. Environ.* **38**, 3501–3515.

[7] Alexandrov, M. D., B. Cairns, C. Emde, A. S. Ackerman, and B. V. Diedenhoven, 2012: Accuracy assessments of cloud droplet size retrievals from polarized reflectance measurements by the research scanning polarimeter. *Remote Sens. Environ.* **125**, 92–111.

[8] Huang, Z., J. Bai, T. X. Lu, and X. Y. Hou, 2013: Stray light analysis and suppression of panoramic annular lens. *Opt. Express.* **21**, 10810–10820.

[9] Oh, E., J. Hong, S. W. Kim, Y. Park, and S. Cho, 2016: Novel ray tracing method for stray light suppression from ocean remote sensing measurements, *Opt. Express.* **24**, 10232–10245.

[10] Hendler, R. W., C. M. Meuse, T. Gallagher, J. Labahn, J. Kubicek, P. D. Smith, and J. W. Kakareka, 2015: Stray light correction in the optical spectroscopy of crystals. *Appl. Spectrosc.* **69**, 1106–1111.

[11] Laherrère, J. M., L. Poutier, T. B. Dibat, O. Hagolle, C. Baque, P. Moyer, and E. Verges, 1997: POLDER on-ground stray light analysis, calibration, and correction. *Proc. SPIE* **3221**, 132–140.

[12] Iwasaki, A., and E. Oyama, 2005: Correction of stray light and filter scratch blurring for ASTER imagery. *IEEE T. Geosci. Remote Sens.* **43**, 2763–2768.
[13] Gerace, A., and M. Montanaro, 2017: Derivation and validation of the stray light correction algorithm for the thermal infrared sensor onboard Landsat 8. *Remote Sens. Environ.* **191**, 246–257.
[14] Zong, Y., S. W. Brown, B. C. Johnson, K. R. Lykke, and Y. Ohno, 2006: Simple spectral stray light correction method for array spectroradiometers. *Appl. Opt*. **45**, 1111–1119.
[15] Feinholz, M. E., S. J. Flora, S. W. Brown, Y. Zong, K. R. Lykke, M. A. Yarbrough, B. C. Johnson, and D. K. Clark, 2012: Stray light correction algorithm for multichannel hyperspectral spectrographs. *Appl. Opt.* **51**, 3631–3641.
[16] Hagolle, O., A. Guerry, L. Cunin, B. Millet, J. Perbos, J. M. Laherrere, T. B. Dibat, and L. Poutier, 1996: POLDER level-1 processing algorithms. *Proc. SPIE* **2758**, 308–319.

Preferred mode of presentation: Oral